Reliable Mechanical Contacts via Vapor Phase Lubrication

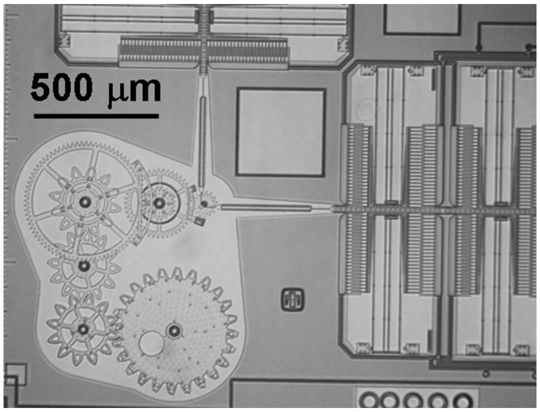

Figure 1: A silicon prototype weapon surety device containing electrostatic actuators (right and top) driving an intermeshing train of six gears.

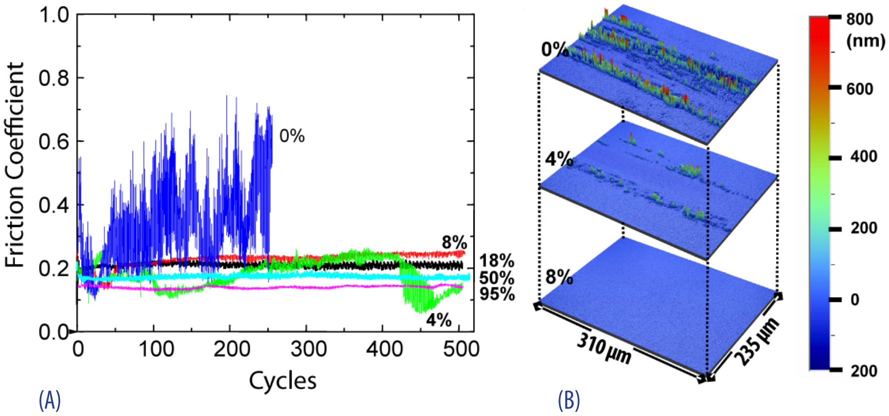

Figure 2: (A) Friction coefficient versus sliding cycles for a silica ball sliding on an oxidized silicon surface in dry N_2 gas (0%) and increasing percentages of the saturation pressure of pentanol. (B) Optical interferometric images of wear tracks for the dry, 4% and 8% cases.

Micromachines now operate with longer lifetimes and greatly reduced wear

The development of complex micron-scale electromechanical devices, or MicroElectroMechanical Systems (MEMS), for weapons has been a very important and unique program at Sandia. An example of a tiny silicon-based mechanical device for weapon safety is shown in Figure 1. The ability to create this functionality with many moving parts at a size scale of millimeters means that safety and use-control systems can be implemented with much lower mass and volume. Commercial applications such as electromechanical locks for information access are also possible. However, due to the small scale, adhesive forces between contacting areas, such as electrostatic, van der Waals and capillary forces, become much more significant and tend to overwhelm the small actuation and mechanical restoring forces. Thus, in order to have reliable, freely-operating MEMS, the contacting surfaces must be "lubricated." Many schemes of lubrication via chemisorbed organic layers have been tried, but the durability of the layers has been insufficient to withstand repeated mechanical contact (Reference 1).

Now a new method to reliably lubricate silicon MEMS has been developed by Sandia and Pennsylvania State University. It can be replenished and does not rely on bulk liquids that introduce viscous losses. "Vapor phase lubrication," or VPL (Reference 2), takes advantage of the adsorption behavior of certain molecules on oxide surfaces, and the physical properties of their condensed phases. At concentrations between 10% and 90% of their saturation pressures, gaseous linear alcohols with three to ten carbon atoms adsorb on oxide surfaces with a thickness of two monolayers or less. This means that pentanol, for example, can maintain monolayer adsorption at a concentration of 400 parts per million (ppm) in an inert gas. When sliding of silicon takes place in this environment, extraordinarily low wear results (Figure 2). MEMS devices operated in this environment exhibit unprecedented operating life. The device in Figure 1 operating in 400 ppm pentanol vapor, was stopped for inspection after running for half a billion revolutions, with no detectable wear.

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Several other types of silicon devices have been operated using alcohol for VPL, with similar results. Also, surface chemical analysis with high spatial resolution, surface sensitivity and chemical specificity is essential for understanding the reactions taking place during VPL. For example, Figure 3 demonstrates that the same chemical processes that occur in macroscale sliding tests (Figure 2) are also happening at the MEMS scale. Pin-on-disk measurements suggest that this lubrication approach also works on stainless steel surfaces.

Application of VPL to electromechanical devices critical to Sandia's mission is promising, and significant basic research and technology maturation are ongoing. The overall effort is to understand the surface chemistry, to tailor the vapor species for particular surfaces, to produce lower friction response, and to develop robust delivery schemes so that the environment for VPL can be produced and maintained over the desired operating temperature range.

References

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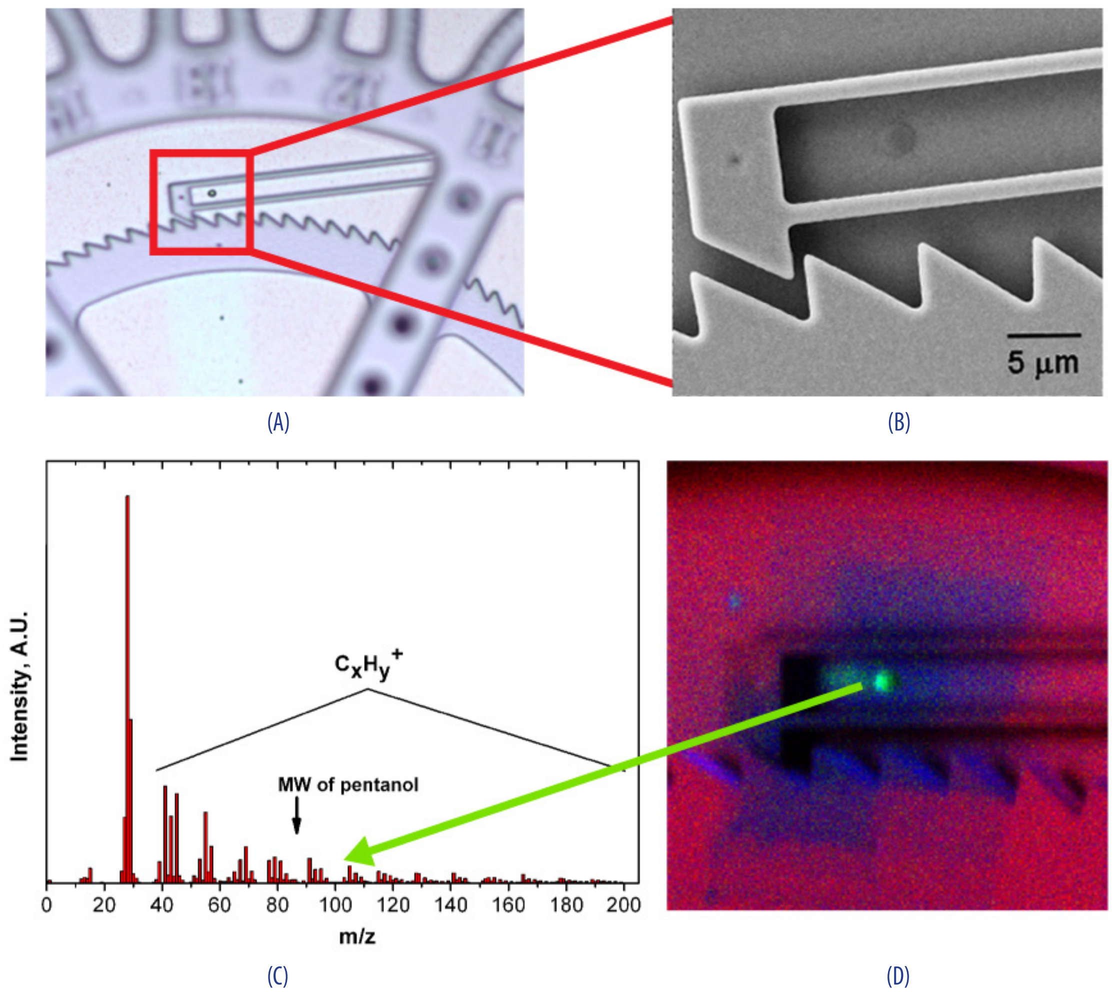

Figure 3: (A) Section of a MEMS rotary actuator operated 5x10^8 revolutions in pentanol vapor, showing the thermally-actuated tooth (B) that engages the wheel for rotation. (C) The time-of-flight secondary ion mass spectroscopy corresponding to surface reaction products , and a spatial map of the reaction product (green area in D).

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